Defining and Validating Embedded Computer Software Requirements Using the ECS, OTPM and IPFA

23rd Software Engineering Workshop
December 3, 1998

Dr. John H. Manley
University of Pittsburgh
Computing Technology Transition, Inc. (CTTI)
jmanley@engrng.pitt.edu

AGENDA

- Software-Dependent “Real-Time” Systems
- ECS Experience and Research Interest
- Aerospace/Weapon Systems Special Attributes
- Industry “Embedded Software” Acquisition Issues
- Manufacturing Systems Attributes and Tools
- OTPM and IPFA Solution for “Manufacturing”
- Manufacturing Industry Application Results
- Summary and Conclusions

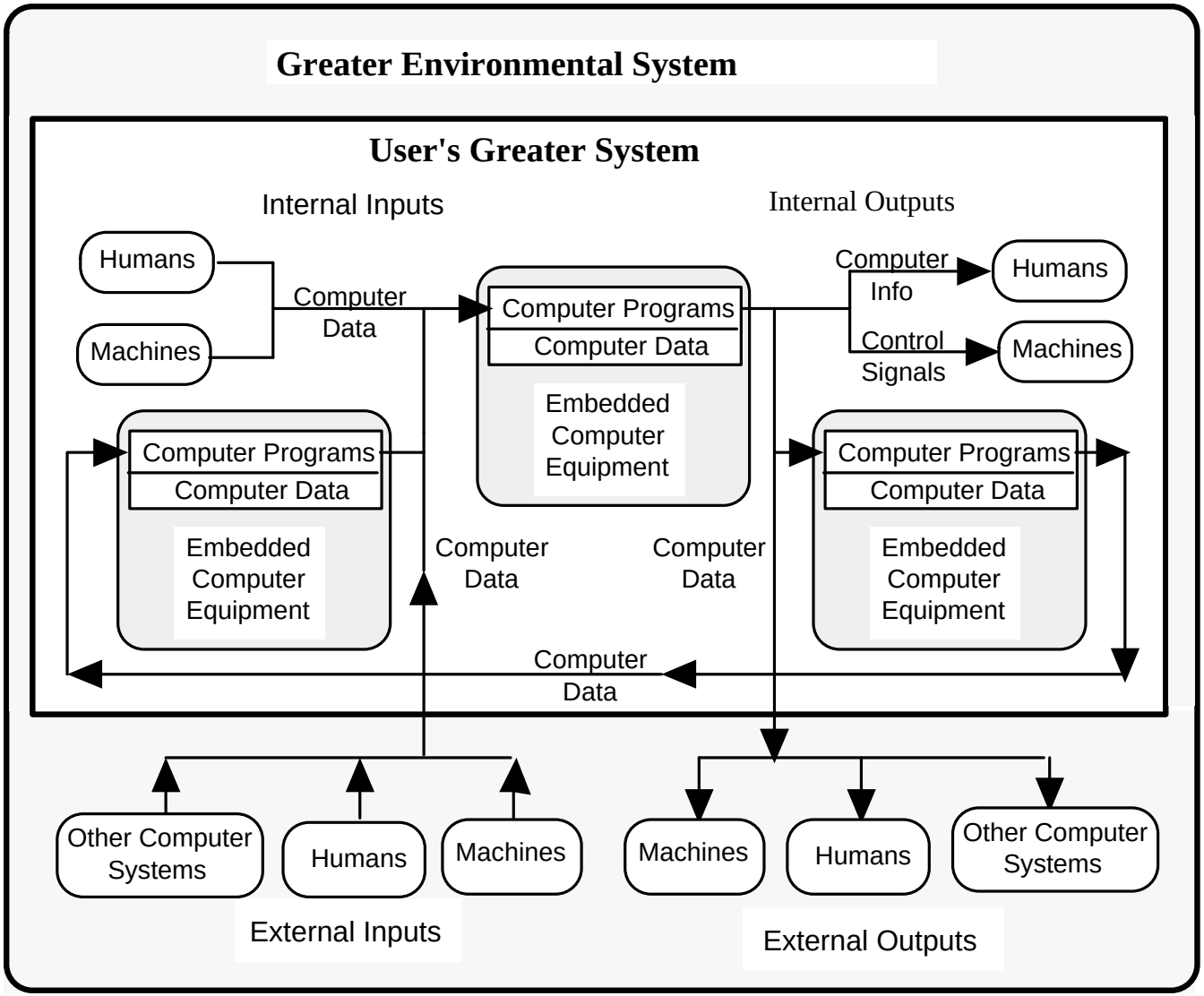
SOFTWARE-DEPENDENT SYSTEMS

- Boeing 777
- U.S. Air Traffic Control System
- Aluminum Sheet Rolling Mill
- Military Command and Control System
- Automobile Assembly Plant
- Space Shuttle Operations Center
- Your New Automobile
- Interactive Videoconferencing System

ECS EXPERIENCE—RESEARCH INTEREST

- **Air Force Career—Lt Col, USAF, Retired**
  - Ammunition/EOD/Nuclear Weapons Loading Officer—SAC
  - Master Navigator, Bomb-Nav Instructor, Flight Examiner
  - Designed and Developed Command and Control Systems
  - Formulated USAF “Embedded Software” Acquisition Policy
- **Civilian Industry and Academic Career**
  - Improved DoD-wide Software Acquisition Policies at APL
  - Directed Software Technology for $2 billion ITT System
  - First Full-time Director, DoD Software Engineering Institute
  - Officer and Director of Software-Related Companies
  - Professor of IE and Manufacturing Systems Engineering

EMBEDDED COMPUTER SYSTEM (ECS) MODEL



SOURCE: Dr. John H. Manley

AEROSPACE WEAPON SYSTEMS ATTRIBUTES

- **True "Real-Time" Operation—Vehicle Keeps Moving**
  - Complex and dynamic mathematical algorithms
  - System architecture must define all human-machine-computer information/communication interfaces
- **DoD Aerospace Systems Require Complex Software for:**
  - Command and control interfaces—open and secure
  - Electronic warfare detection and countermeasures
  - Weapon systems operation and accuracy
  - Adverse weather and terrain avoidance operation

Aircrew Lives Depend on Reliable Software!

MAKING “INVISIBLE” SOFTWARE VISIBLE

- **Known to the DoD as “Invisible Cloth” in the 1970s**
  - Humans and hardware are “visible” physical objects
  - Software involves a series of “invisible” intellectual objects
  - Software development is “invisible” compared to hardware
- **Required Information for ECS Development**
  - “Human” system specifications must include detailed physical profiles and position descriptions
  - “Hardware” system specifications must include detailed architectural and engineering drawings
  - “Computer Program” system specifications must include detailed computer program data input/information output, and information system interface and timing requirements

MANUFACTURING INFORMATION SYSTEMS

High quality information is necessary for (1) effective operation of manufacturing enterprise supporting equipment, facilities and processes, (2) providing customer and supplier services, and (3) proper operation of computers embedded in so called “intelligent” manufactured products. Therefore:

Reengineering any process in isolation, or products as stand-alone entities, is not advisable in today's manufacturing enterprise without also addressing related business, engineering, and other enterprise product and process information systems.

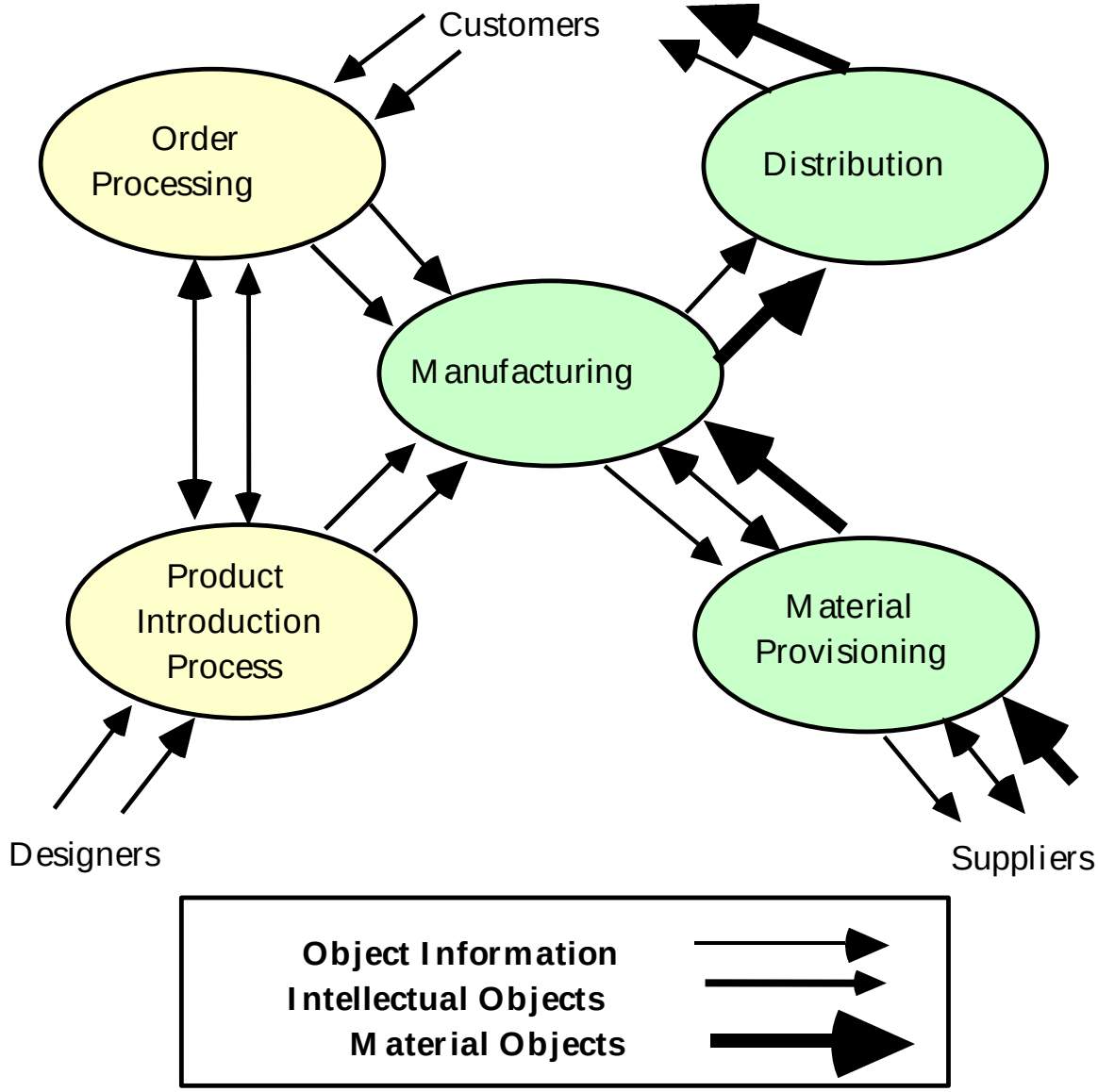
MANUFACTURING SYSTEMS ATTRIBUTES

- **Manufacturing Processes**
  - Repetitive, linked, input-process-output phases
  - Phases transform physical and intellectual objects from one state to another
- **Manufacturing Engineering—Micro Focus**
  - Physical object phase transformations are normally designed by:
    - Mechanical, Electrical, Chemical, and/or Metallurgical Engineers
  - Intellectual object transformations are normally designed by:
    - Industrial, Architectural, and/or Software Engineers
- **Manufacturing <u>Systems</u> Engineering—Macro Focus**
  - Repetitive "earth-to-earth" transformation processes, e.g., automobiles
  - Repetitive enabling processes, e.g., supply chain, finance, management
  - Physical and intellectual object combinations, e.g., automated systems
  - All "engineers" (subject matter experts) are required to work on teams

MANUFACTURING SYSTEMS ENGINEERING DESIGN TOOL EXAMPLES

- **Human component design tools**
  - Job descriptions
  - Ergonomic analyses
- **Machine component design tools**
  - Engineering drawings
  - Simulation models
- **Embedded computer component design tools**
  - Process flow analyses (PFA)
  - Information Process Flow Analyses (IPFA)

TRANSFORMATION PROCESSES AND INFORMATION SYSTEMS



ECS SOFTWARE (RE)ENGINEERING TOOLS

- **Minimum Essential Information (MEI) Guideline:** Remove redundant and/or unnecessary information to simplify control system requirements and insure that necessary and sufficient information is provided where and when required.
- **Embedded Computer System (ECS) Model:** Identify human, computer, and machine data exchange relationships to help define internal and external physical communication requirements.
- **Process Flow Analysis (PFA):** Industrial Engineering method for increasing the efficiency of any real-time repetitive process.
- **Information Process Flow Analysis (IFPA):** During a PFA, identifies extraneous, garbled or missing information necessary for efficient operation of all types of process control loops.
- **Data Design Tools:** Transform high-level IFPA-derived data requirements into programmable data elements.

MINIMUM ESSENTIAL INFORMATION (MEI)

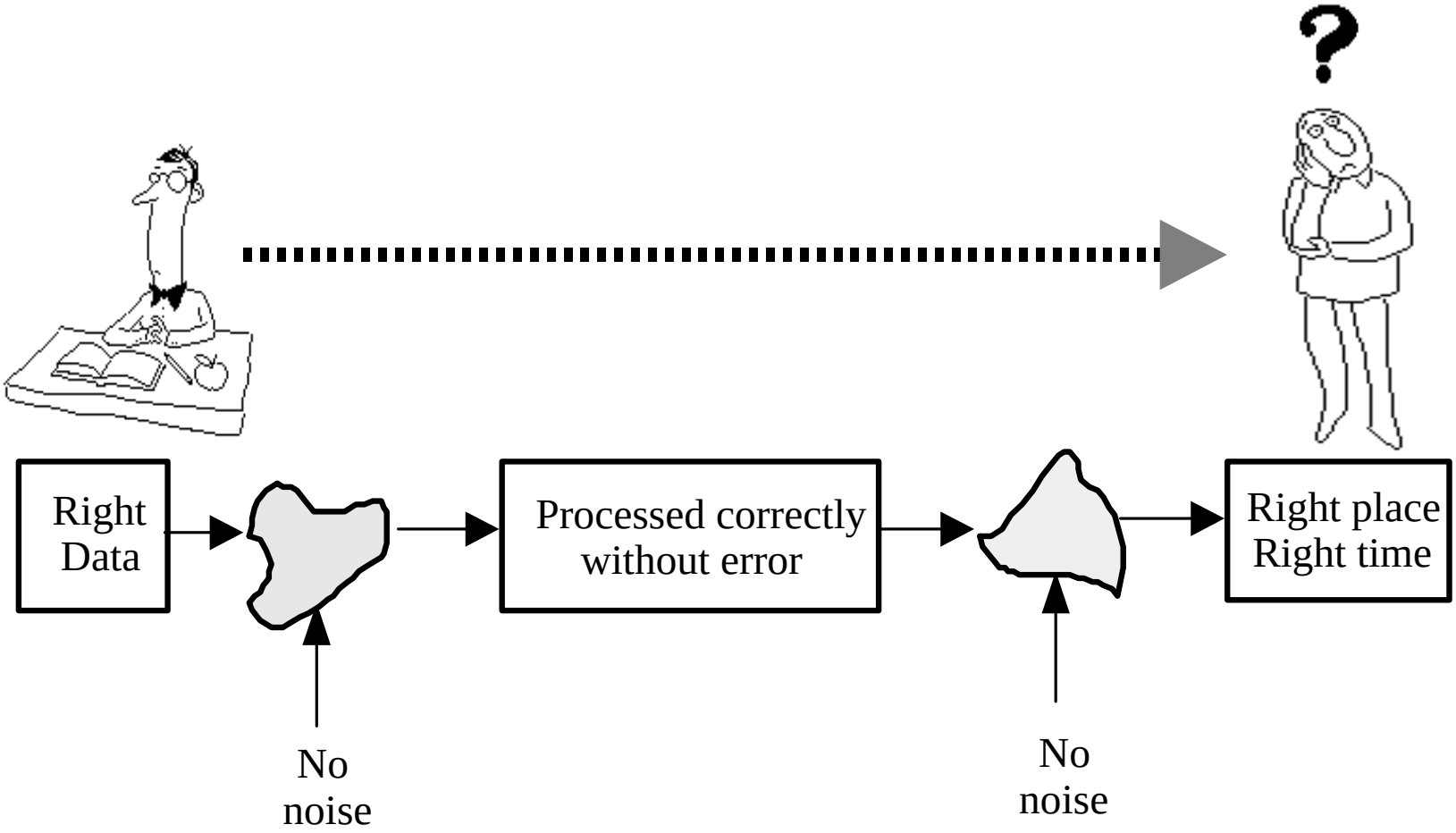
One key to embedded system software engineering success is for *everyone* to actively and continuously identify and reduce the amount of information they generate, use, and store at every point in the life cycle. Recommended guidelines:

- DO NOT retain preliminary process descriptions and similar documentation
- DO NOT hold unnecessary meetings
- DO NOT require or generate FYI reports
- DO eliminate all unimportant information
- DO tell others that you don't need that data
- DO NOT try to manage by paper product alone
- DO develop and use tangible technical progress indicators

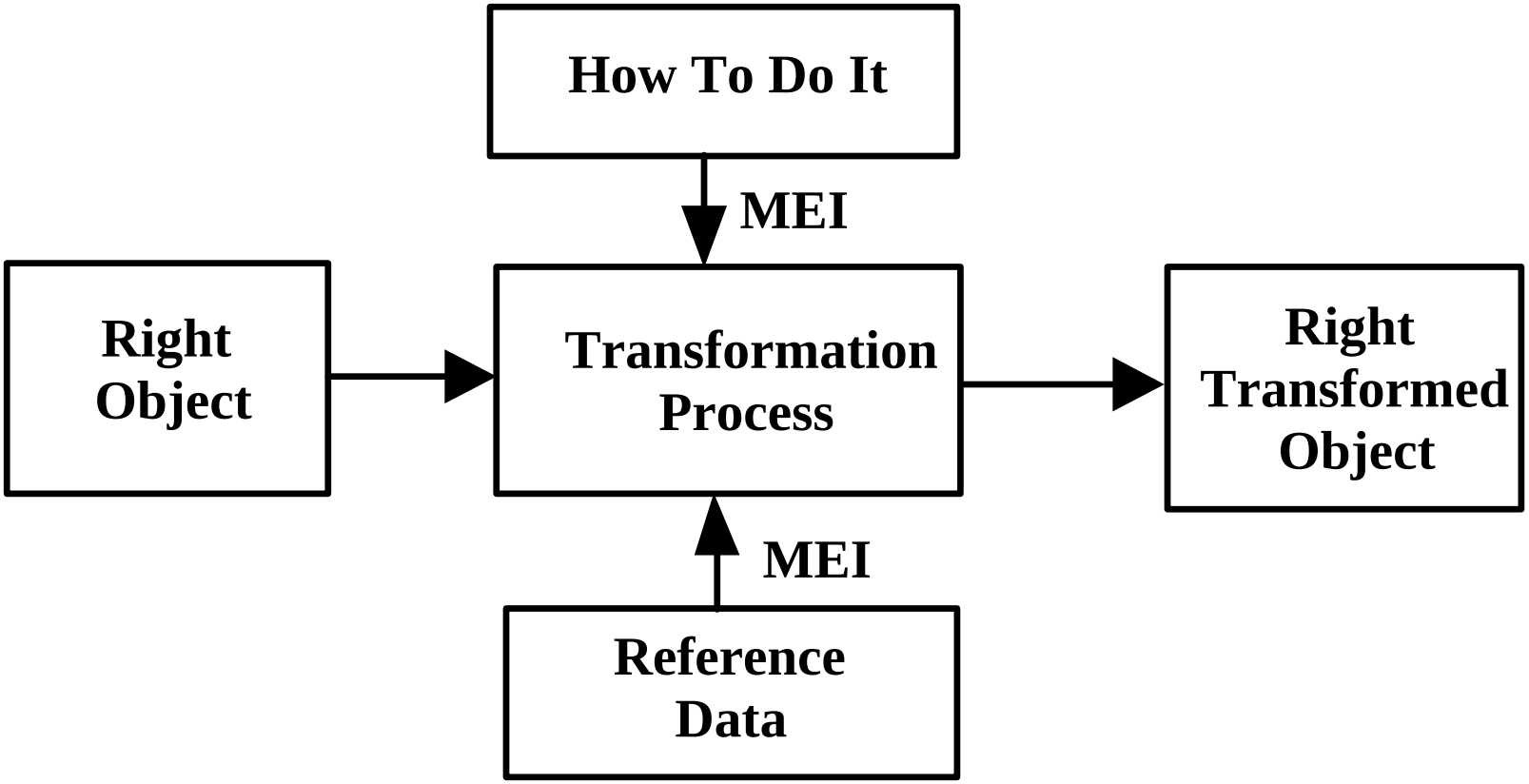
OTPM-BASED ARCHITECTURAL MODELING

- **Object Transformation Process Model (OTPM)**
  - Provides a top-level architectural framework for designing, integrating, troubleshooting, and reengineering enterprise-wide management, finance, engineering, and quality assurance process control information systems.
  - Used as guide for IPFA team members to ensure mutual understanding of reengineering project requirements.
  - Provides comprehensive framework for defining embedded software input/process/output specifications.

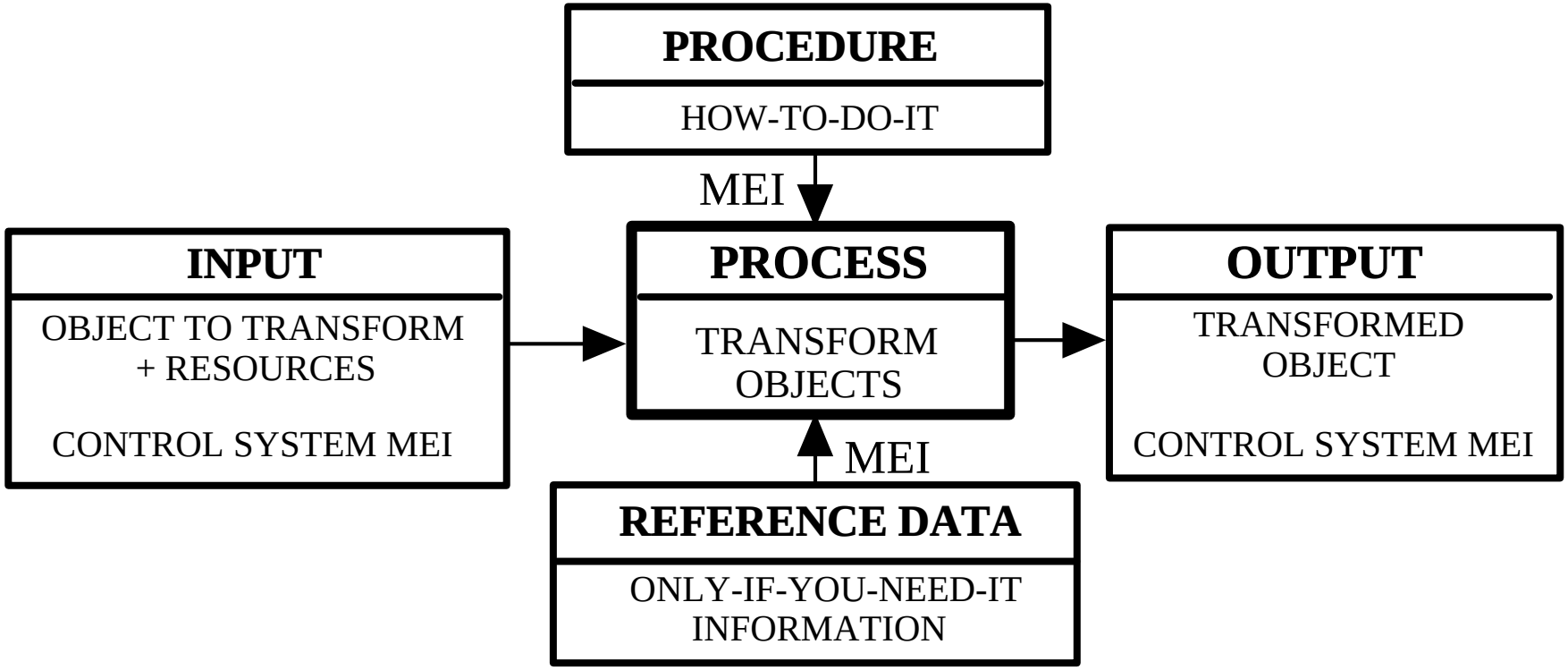
OTPM INFORMATION CONCEPT



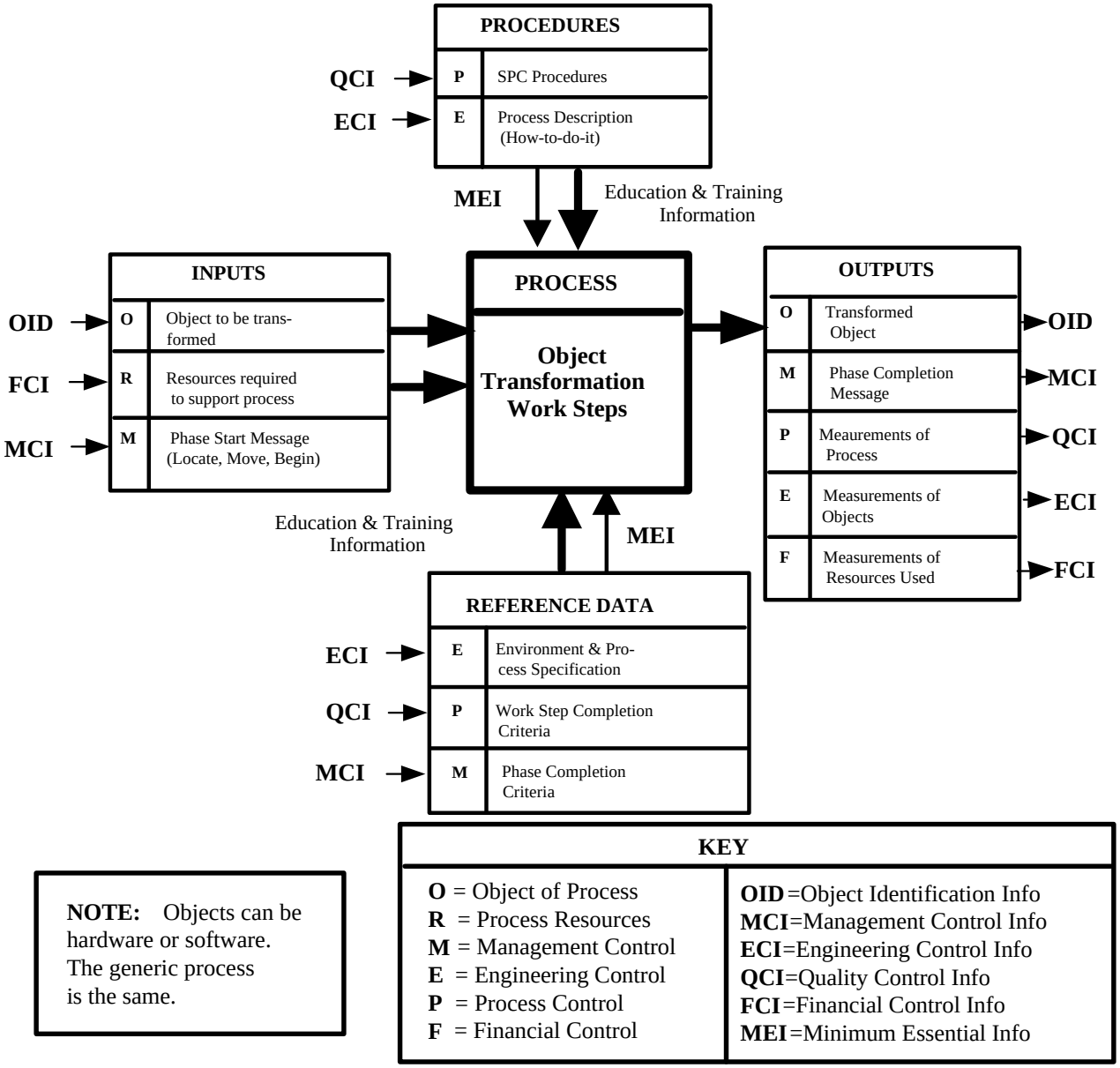
OBJECT TRANSFORMATION PROCESS CONCEPT



OTPM GENERIC MODEL



OBJECT TRANSFORMATION PROCESS MODEL (OTPM)



ECS, OTPM, and IPFA FIELD TEST RESULTS

- **General Motors:** Reengineered plastic molding plant process control information systems—$1.8 million annual saving
- **Bloom Engineering:** Improved reuse of design information for developing metallurgical furnace control systems
- **PDVSA (Venezuela):** Standardized 70 different procedures for developing purchase requisitions for offshore buyers
- **Delphi Packard Electric:** Used OTPM-based information system analysis to solve ignition cable loose core problem
- **H.J. Heinz:** Developed statistical process control system for peach puree manufacturing resulting in zero scrap loss
- **Elliot Company:** Used PFA and IPFA to improve supply chain receiving process for gas turbine generator manufacturing

SUMMARY AND CONCLUSIONS

- Field tests by practicing engineers and consulting by the author in manufacturing companies have shown that an OTPM-based IPFA analysis of any complex, repetitive, real-time, physical or intellectual object transformation process can define MEI and ECS human, machine and embedded computer information requirements.
- The IPFA-derived ECS input/output/procedure/reference information provides system-engineered embedded computer software requirements for reengineering object transformation processes.
- Implementation of IPFA recommendations for software changes by manufacturing companies have all proved to increase their overall efficiency and competitiveness.